# CUORE: An Experiment to Investigate for Neutrinoless Double Beta Decay by Cooling 740 kg of $TeO_2$ Crystals at 10mK


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on behalf of the CUORE Collaboration

# CUORE collaboration

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# Outline

- CUORE Experiment: what, why, how, where and when
- Thermal detectors
- Low temperature CUORE detectors
- Detector Sensitivity
- Surface Sensitive Bolometers
- CUORICINO: a small scale system, results
- CUORE vs. CUORICINO
- CUORE state of art

# The CUORE experiment

- What:

  Investigate on $0\nu$ Double Beta Decay: $(A,Z) \rightarrow (A, Z+2) + 2e^-$

- Why:

  Measure or set a limit on $\nu_e$ mass, test SM.

- How:

  Cooling 740 kg of $^{130}TeO_2$ @ T=10mK, measuring the $\Delta T$ due to the thermalisation of $2e^-$ emitted with Q=2568 keV

- Where and when:

  INFN Gran Sasso National Laboratory (Italy), Data taking starting 1st Jan 2010.

# What: investigate on Neutrinoless Double Beta Decay

## Decay modes:

① $(A,Z) \rightarrow (A,Z+2) + 2e^- + 2\nu_e$ ← 2ν Double Beta Decay allowed by the Standard Model already observed ; $\tau \geq 10^{19}$ y

② $(A,Z) \rightarrow (A,Z+2) + 2e^-$ ← neutrinoless Double Beta Decay (0ν-DBD) open discussion on its observation $\tau \geq 10^{25}$ y

③ $(A,Z) \rightarrow (A,Z+2) + 2e^- + \chi$ ← Double Beta Decay with Majoron (light neutral boson) never observed ; $\tau > 10^{22}$ y

Processes ② and ③ would imply new physics beyond the Standard Model

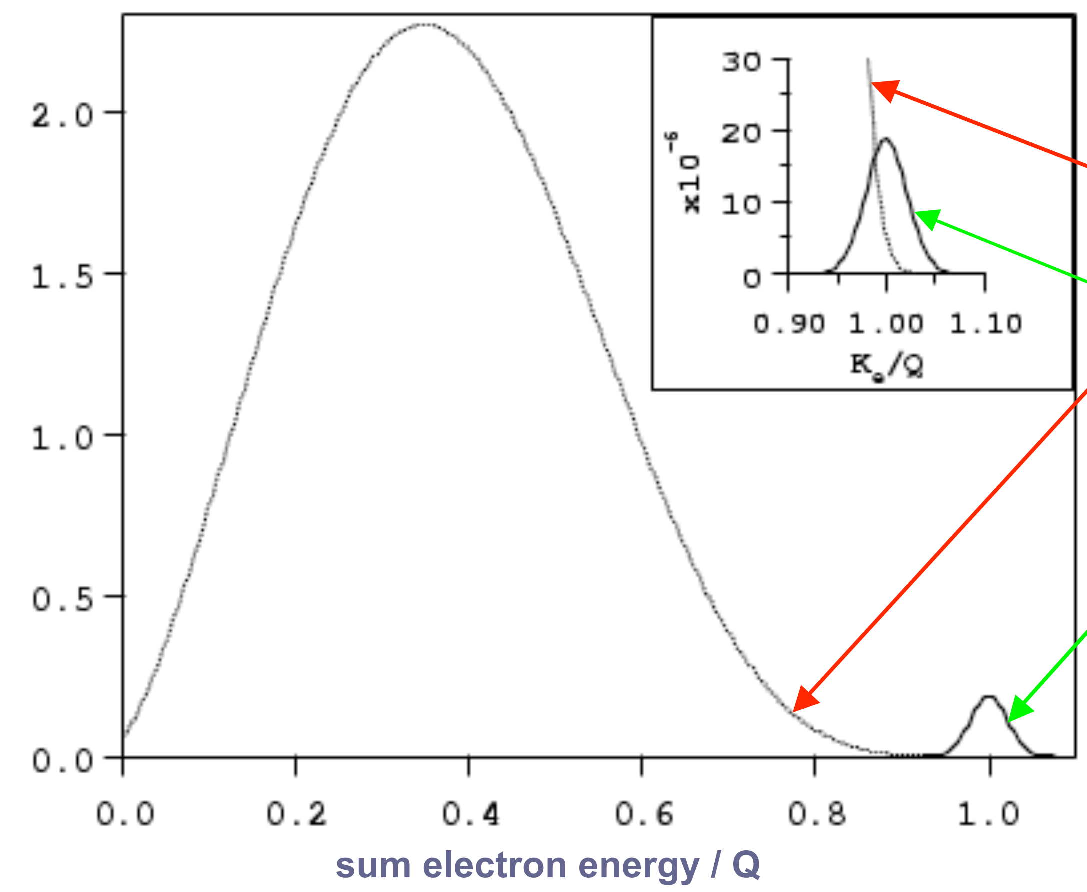
violation of lepton number conservation

# Why: Measure or set a limit on $\nu_e$ mass, test SM

- Neutrino oscillations has been observed.
- The differences between the square of the neutrino mass eigenvalues is different from zero ($\tau_{1/2} \neq \infty$).
- $m_\nu \neq 0$ , but its absolute value cannot be determinated.
- experiments on $0\nu$DBD life time could measure or set a limit on $m_\nu$ ($\tau_{1/2}$ ).

# How: measuring the two electrons sum energy spectrum

$(A,Z) \rightarrow (A,Z+2) + 2e^-$




Two neutrino DBD

Continuum with max at

~ Q/3

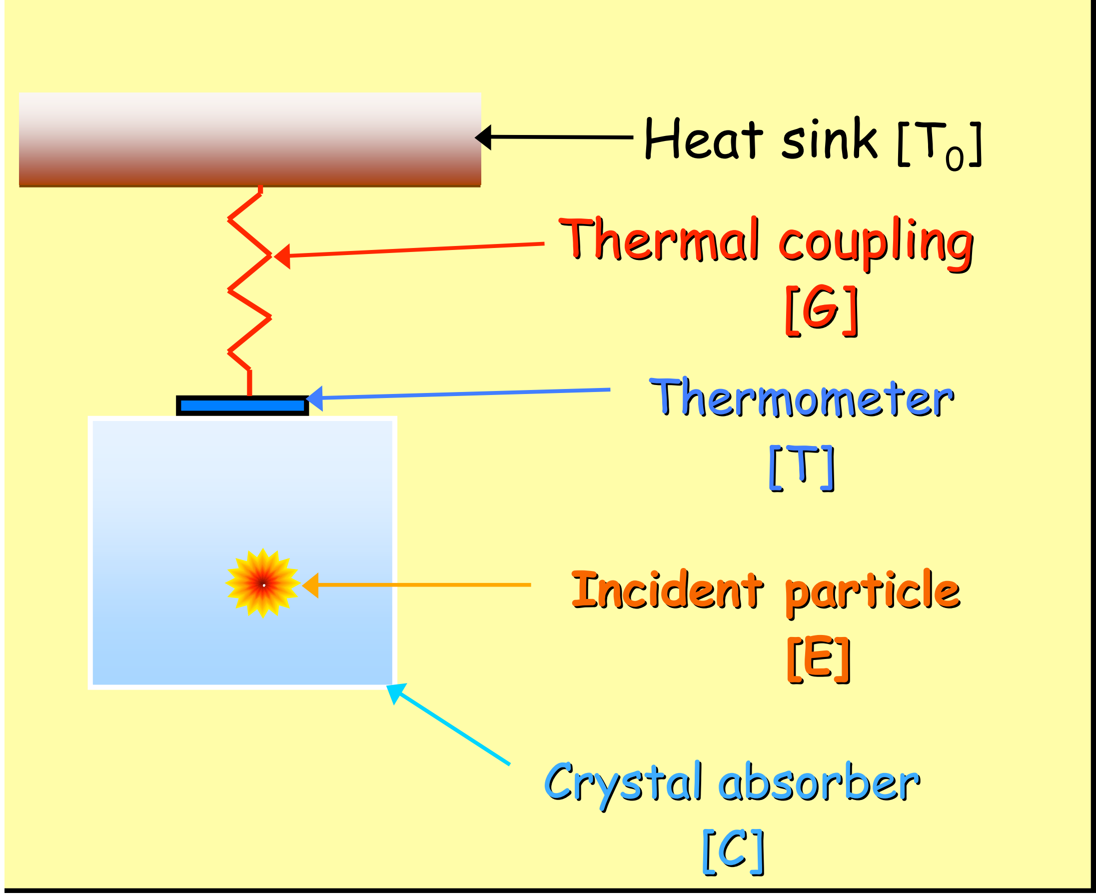
Neutrinoless DBD

Peak at Q=2528 keV

# Technique for measuring the 2e energy spectrum

Thermal detector: direct (indirect)

absorber = (≠) DBD source




A particle release the energy E:

Signal:

$\Delta T = T - T_0 = E/C$

Thermal time constant:

$\tau = C/G$

# Why do we need very low T ~ 10mK ?

- Thermodynamic signal: $\Delta T = \Delta E/C = 2528$ keV/C
  - $C \propto T^3 \rightarrow C(760g,\ TeO_2\ @\ 10mK) \cong 2\ 10^{-9}$ J/K
  - $\Delta E = 2528$ keV $\rightarrow \Delta T \cong 0{,}2$ mK
- Conversion $\Delta T \rightarrow \Delta V$: NTD Ge thermistor
  - $R(T;\ R_0, T_0) = R_0 \exp(T_0/T)^{1/2}$
- Thermodynamic Noise: statiscal fluctuations of $\Delta U$ $<\Delta U^2> = k_B C T^2 \rightarrow \Delta U^{min} \cong 1{,}7\ 10^{-18}$ J = 11 eV (lower Energy resolution)

  $\Delta T^{min} = T(k_B/C)^{1/2} \cong 7$ nK
- R(NTD) = 0,1÷ 10 GΩ ⇒ low Johnson noise current
  - high impedance paths ⇒ good dielectric properties.
  - low impedance paths ⇒ superconducting wiring.

# Thermal Detectors characteristics ($T \approx 10mK$)

☺ All the deposited energy is measured.

☺ The detector is fully sensitive.

☺ Wide material choice.

☺ Slow time response $\tau \approx 1 \div 10^3$ ms $\rightarrow$ no fast electronics needed
Fast signals can be used as a veto for background reduction.

😐 Use radio pure materials for detector and crystal structure.

😐 At T=10 mK: Kapitza resistance, electron-phonon decoupling $\rightarrow$ difficult to construct a full thermal model of the system response.

☹ Very low temperature needed, $T_0 \approx 10mK$ $\rightarrow$ custom made powerful dilution refrigerator.

☹ Need to operate in low radioactivity site $\rightarrow$ underground site.

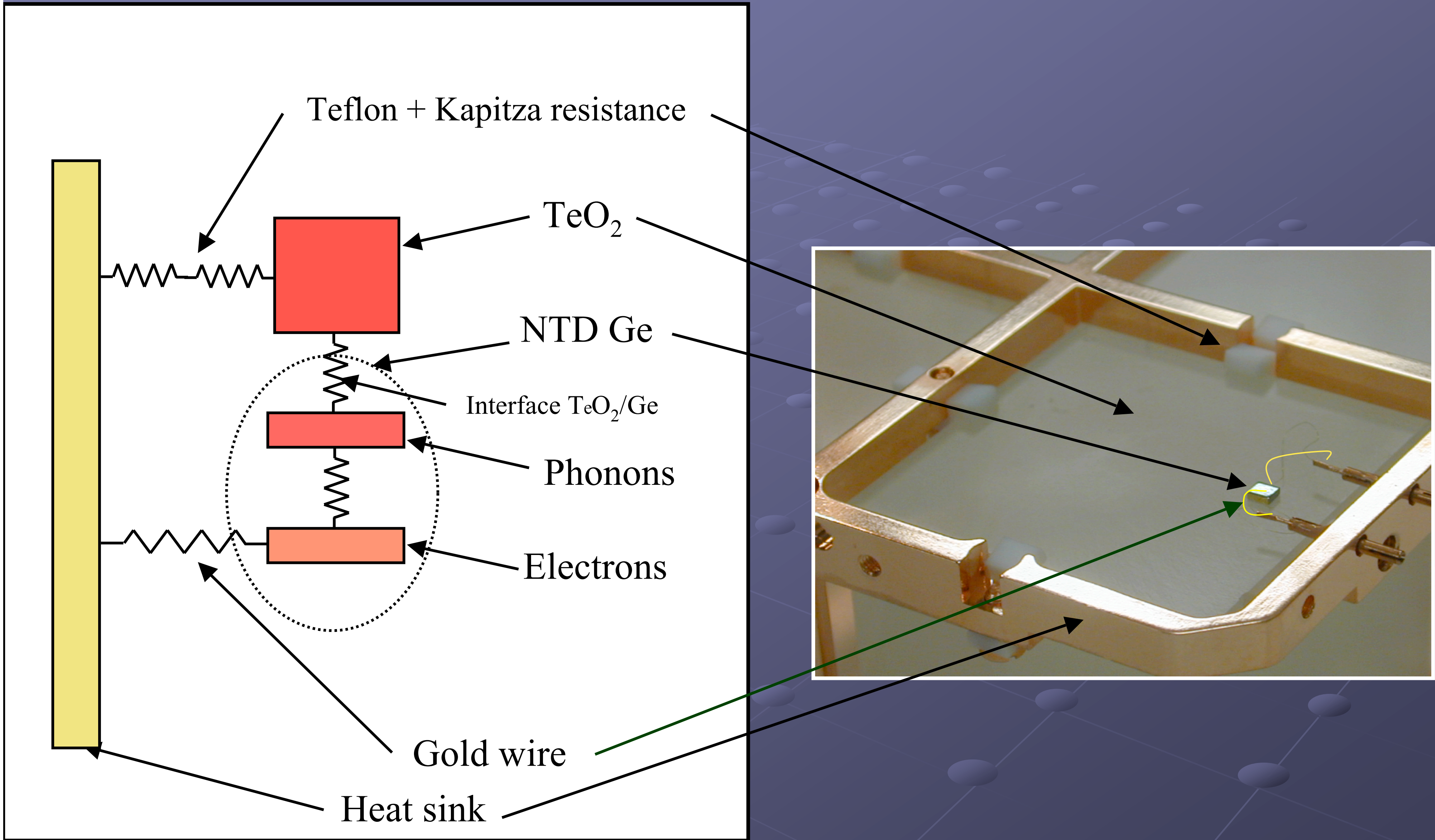
# CUORE (Criogenic Underground Observatory for Rare Events)

- Detector material: 988 (750g $TeO_2$) single crystals, total mass 741 kg.
- Thermometer: Neutron Trasmutation Doped NTD Ge.
- Mechanical holder:  OFHC Cu and PTFE
- Cooling: dilution refrigerator + pulse tubes

# The $TeO_2$ detector:

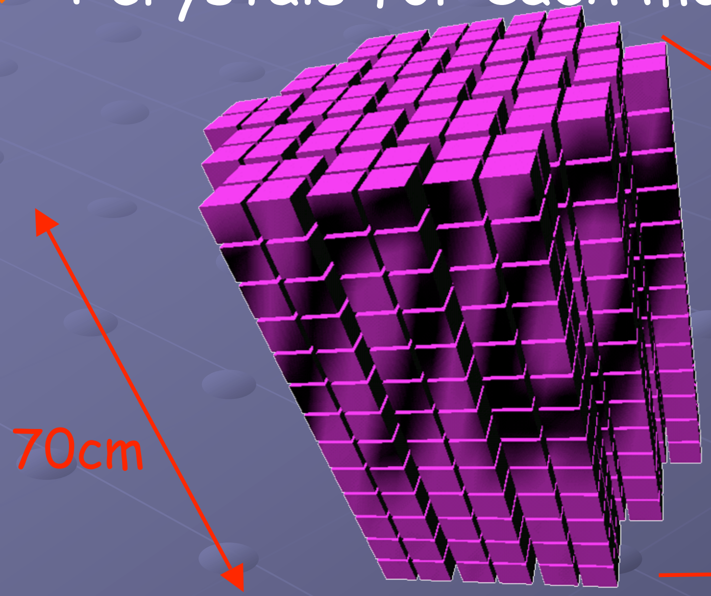
- Active isotope: $^{130}Te$
  - natural abundance: a.i. 33,9%
  - transition energy: $Q_{\beta\beta}$= 2529 keV
  - predicted half life: $\langle m_\nu \rangle \approx 0,3$ eV $\Leftrightarrow \tau_{0\nu} \approx 10^{25}$ years
- 988 $TeO_2$ crystals (750g each)
  - $\Rightarrow$ 741 kg $TeO_2$ granular calorimeter
  - $\Rightarrow$ 600 kg $T_e \Rightarrow$ 203 kg $^{130}Te$

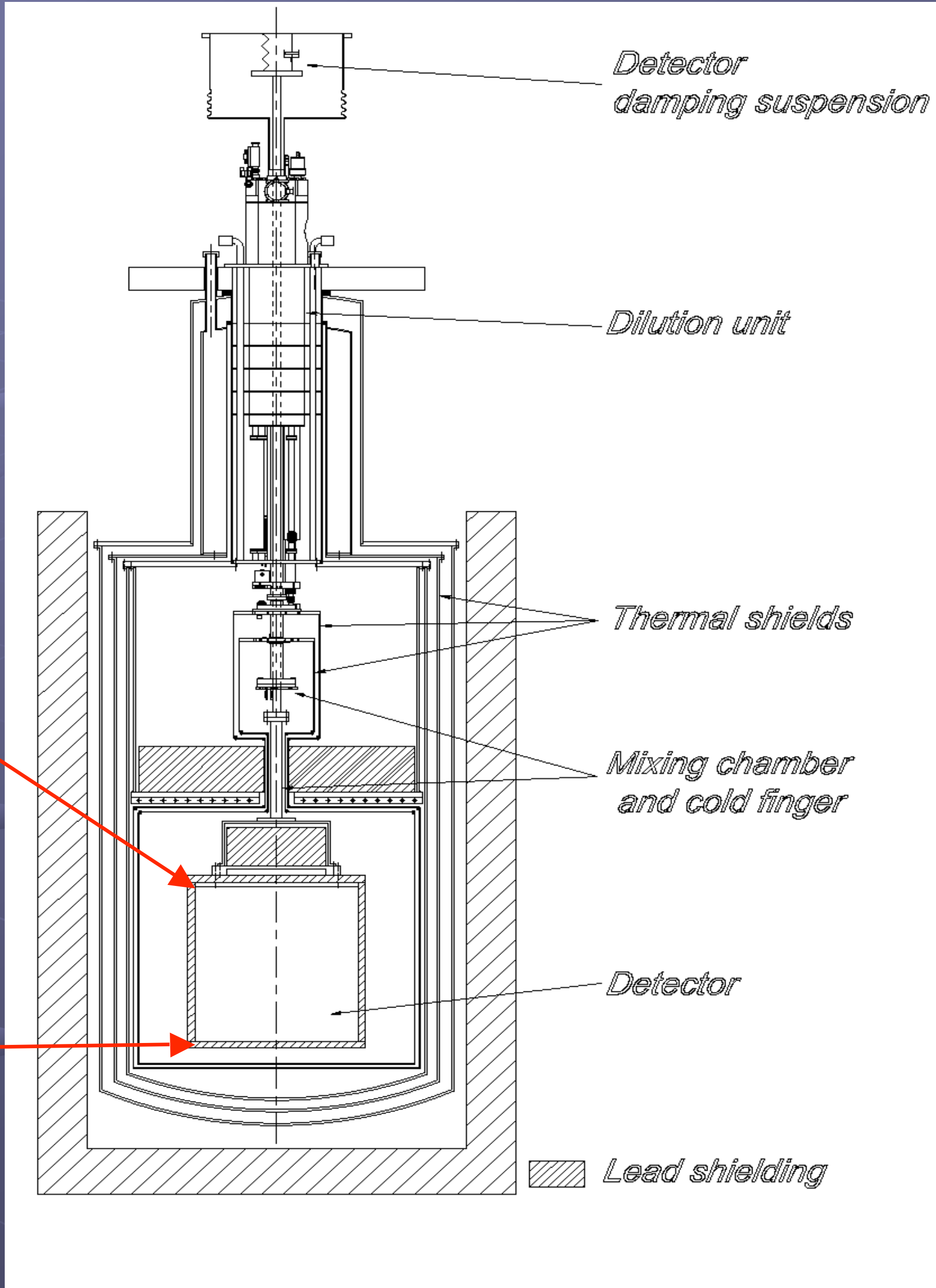
# The $TeO_2$ detector: thermal model



# The CUORE system
(Schematic)

- 19 towers
- 13 modules for each tower
- 4 crystals for each module



# CUORE Sensitivity (predicted):

$$\Sigma(\tau_{1/2}^{0\nu}) \cong 4{,}2\cdot 10^{26}\ \varepsilon\ \frac{a.i.}{A}\sqrt{\frac{M\cdot t_m}{\Delta E\cdot bkg}} = 2{,}1\cdot 10^{26}\ \ \mathrm{y}$$

*ε(efficiency) ≈ 0,8   a.i. (isot. ab.) = 33,9%   A=130*

*M($T_eO_2$ mass) = 600 kg   t (measure) = 5 years*

*ΔE (en. resolution)= 5 keV   bkg = 0,01 c/keV/y/kg*

Background reduction:

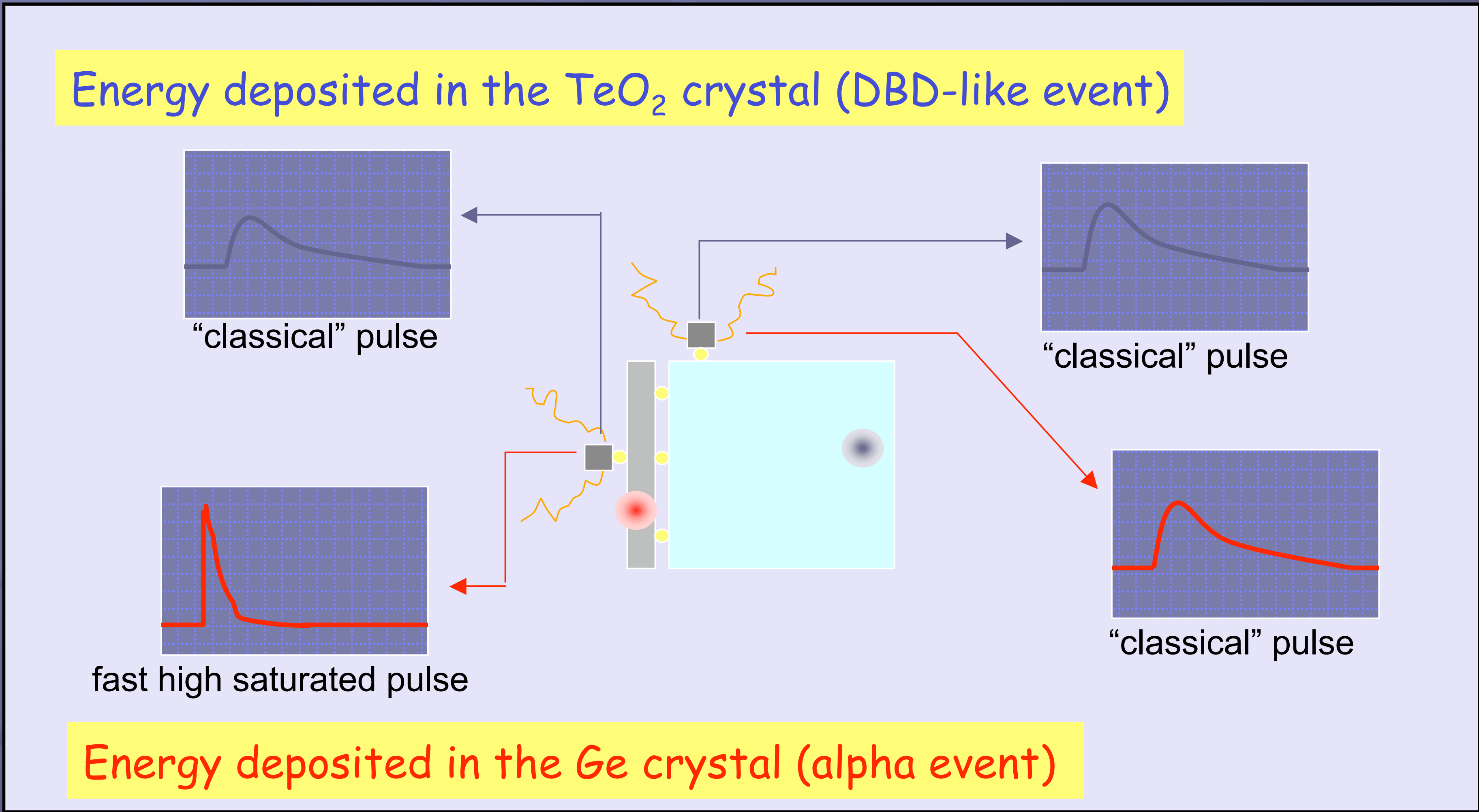
10 on Cu surface contamination

4 on $TeO_2$ surface contamination

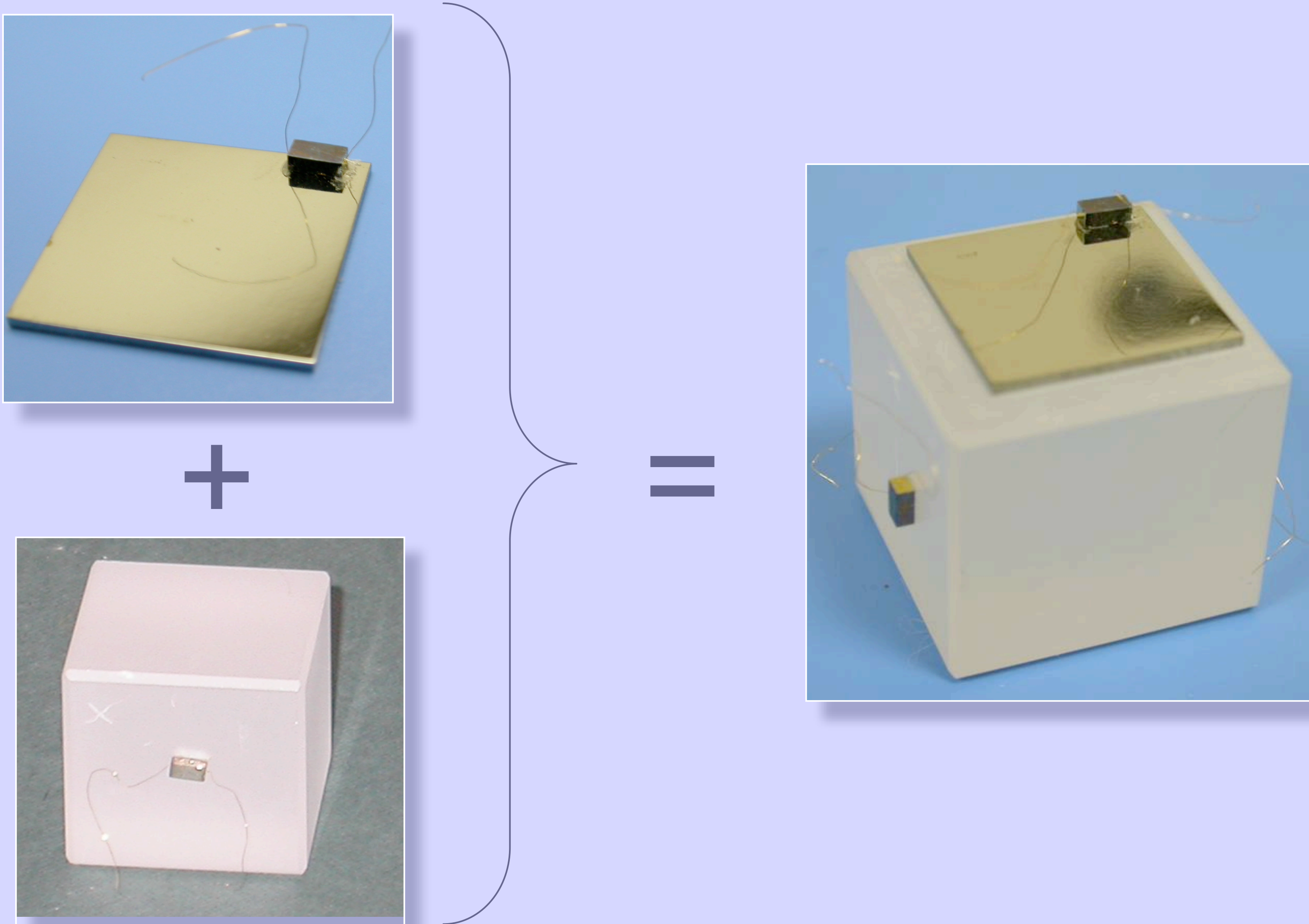
Or use improved rejection methods

# Techniques to reduce bkg by anticoincidences: development of surface-sensitive bolometers

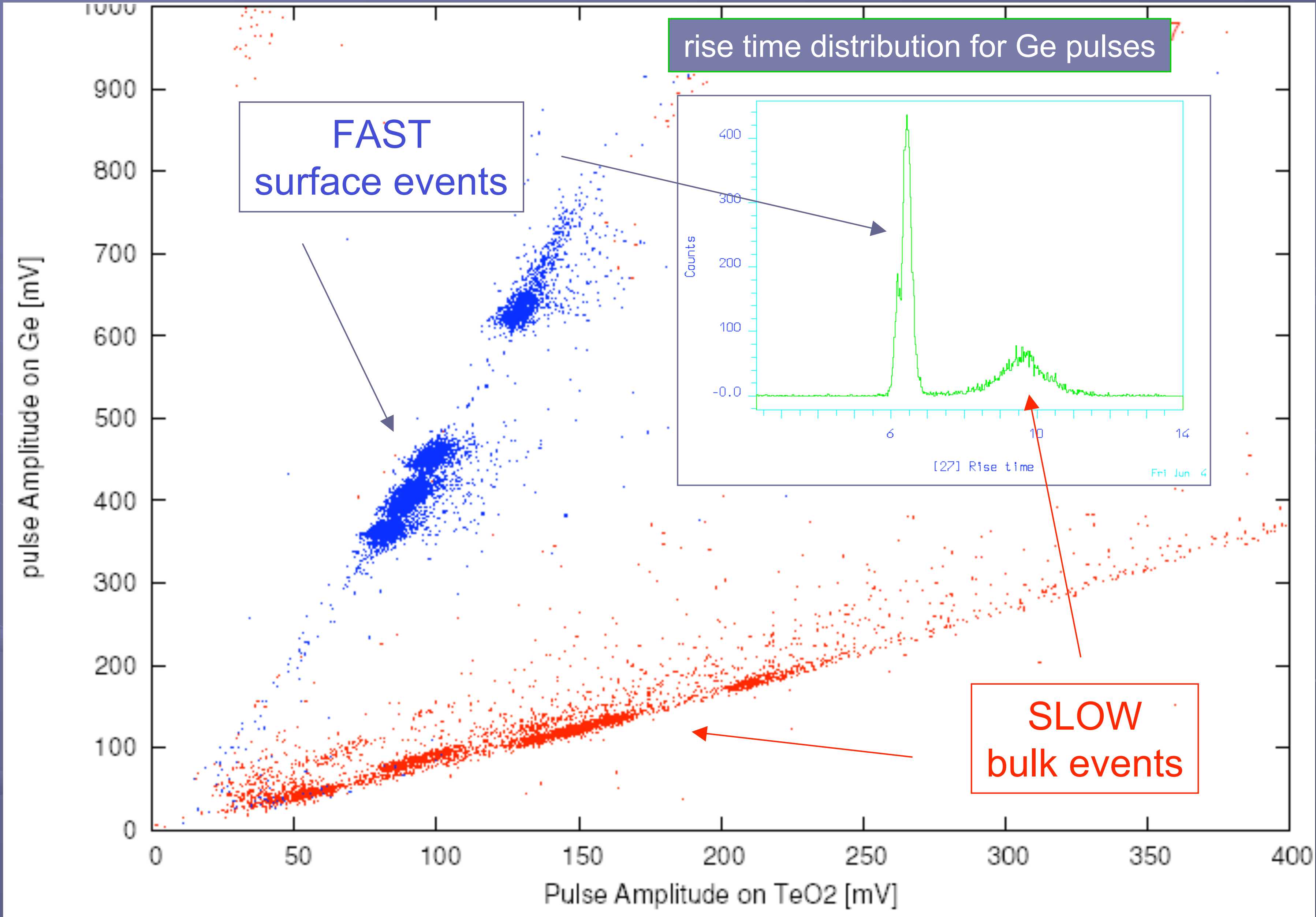
Use a thin Ge (or Si) crystal to make a composite bolometer



# SSB: prototype of a composite bolometer



# Preliminary results

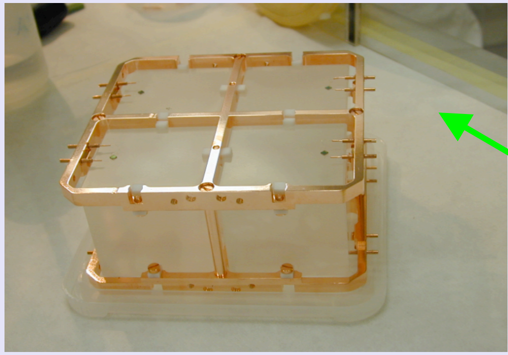


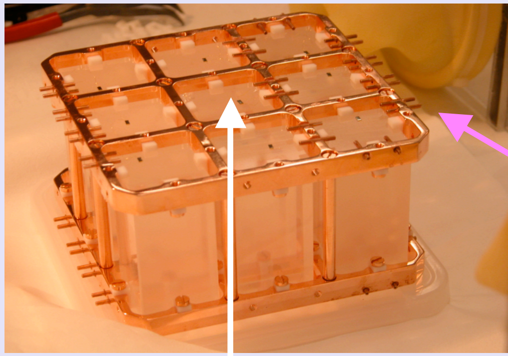
# Test system: CUORICINO - 40,7 kg

CUORICINO = tower of

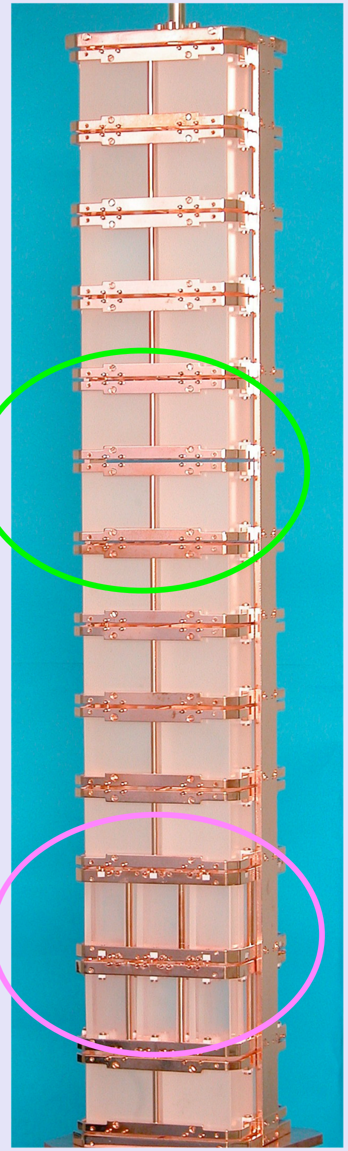
11 mod., 4 detectors , 790 g

2 mod., 9 detectors , 330 g





This detector is completely surrounded by active materials. Useful for BKG origin models



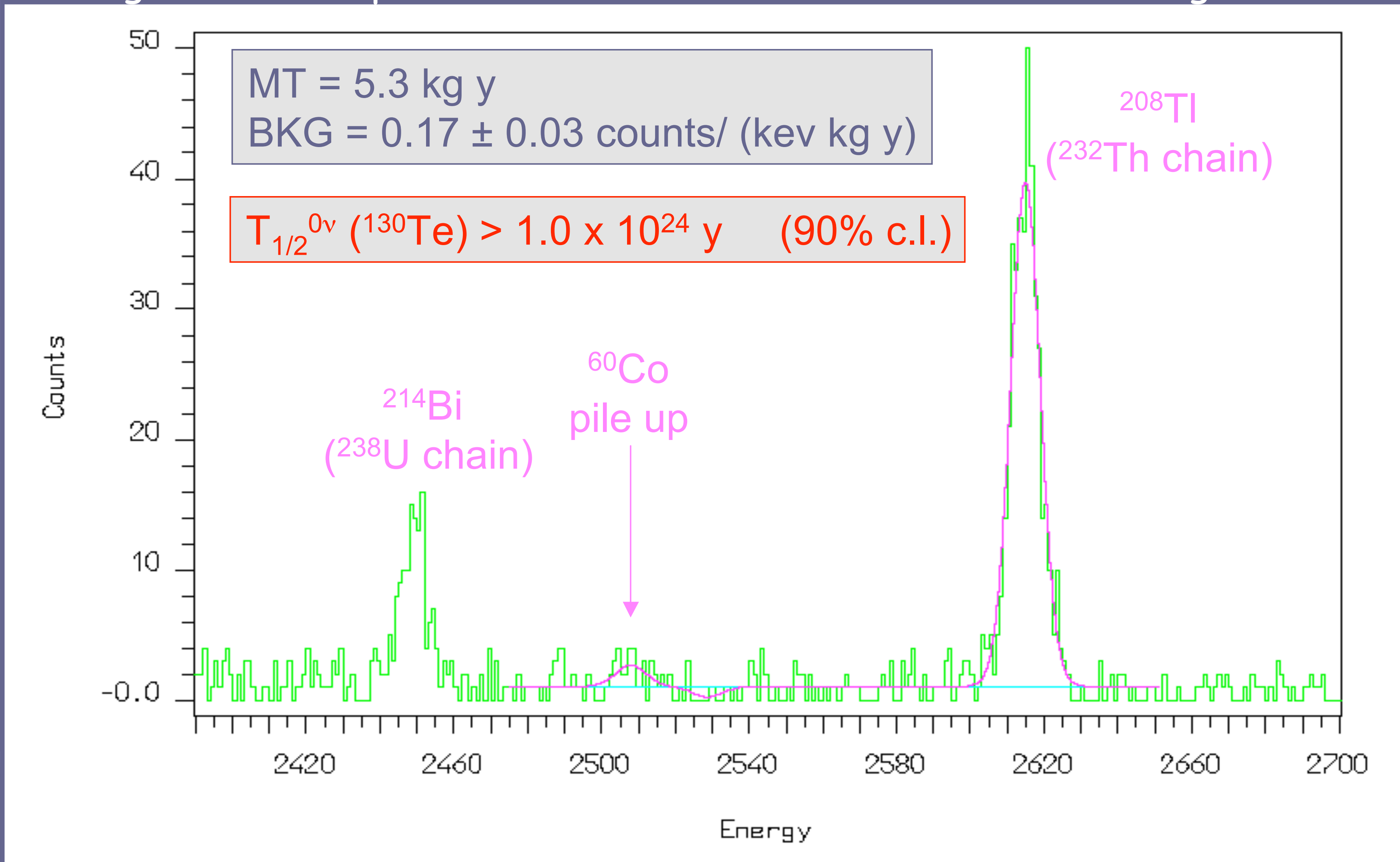
| | | |
|---|---|---|
| # crystals: | 44 | 5x5x5 $cm^3$ |
| | 18 | 3x3x6 $cm^3$ |

TOTAL $^{130}$Te mass:

83 moles

# CUORICINO results

Background sum spectrum of all the detectors in the DBD region

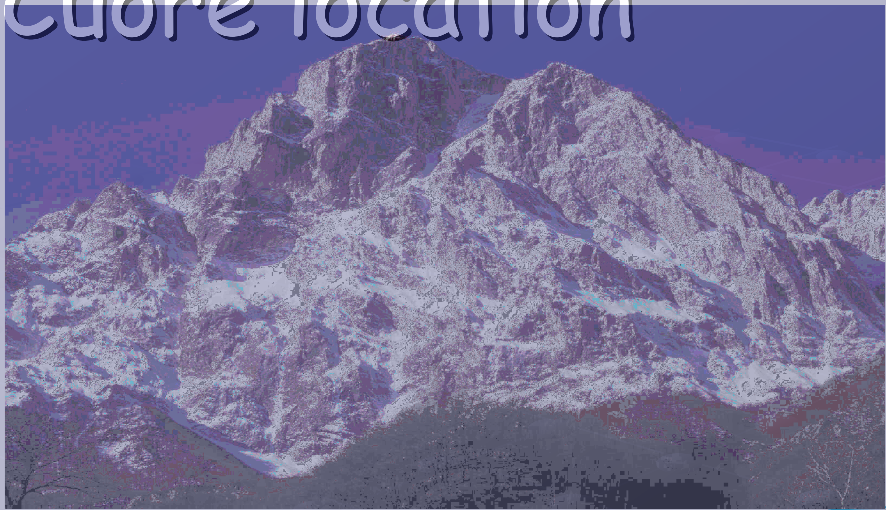


# CUORE vs CUORICINO (a part from $TeO_2$ mass):

- No liquid helium and no superinsulation.
- New set up with optimized shielding structures (BoSi; Roman Pb...)
- New design for crystal holder to reduce the amount of Copper and .. .. to have reproducibility in PTFE thermal contacts.
- High granularity for bkg events identification and reduction
- Improved techniques to reduce background:
  - Surface cleaning techniques
  - Surface sensitive Detectors
  - Scintillating crystals ?

# Cuoricino and CUORE Location

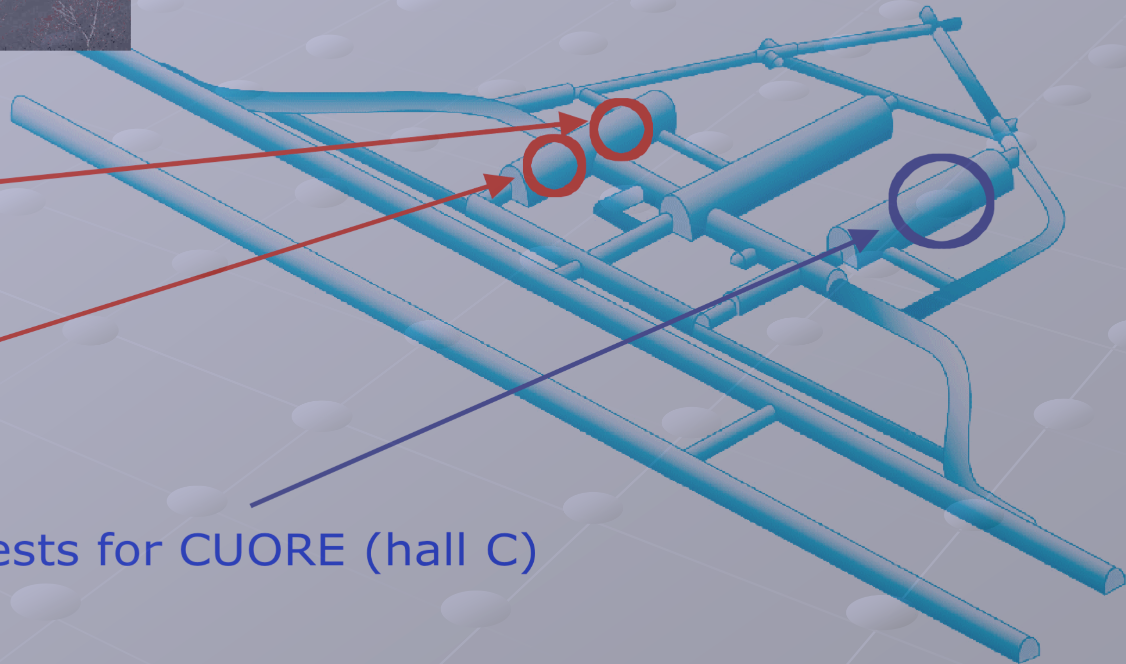
## Cuore location



**Cuoricino experiment is installed in the**

**Underground National Laboratory**
**of Gran Sasso**
**L'Aquila – ITALY**

**the mountain providing a 3500 m.w.e. shield against cosmic rays**



# CUORE Status

2004 Experiment and location approved

2005 Tests on Surface Sensitive Detectors

Tests on new crystals assembly

Design study of new refrigerator

Design and preliminary tests on electronics

DAQ: R&D and first test

………

2010 1st Jan : Start data taking

## CUORICINO - summary of the results:

- Mass: $m\ (TeO_2) = 40{,}7$ kg
- Background: $bkg = 0{,}18 \pm 0{,}02$ c/keV/kg/y
- Energy resolution: $\Delta E = 8$ keV
- Limit on o$\nu$DBD: $S^{1\sigma} \geq 6 \cdot 10^{24}$ y
- Limit on $\nu$ mass: $m_\nu \leq 0{,}11 \div 0{,}60$ eV

# Others Experiments:

| Name | M | Detector | Limit on $m_\nu$ |
|---|---|---|---|
| CAMEO (Borexino) | 65 kg | $C_dWO_4$ | 60 mev |
| EXO I | 1 ton | $C_dWO_4$ | 20meV |
| EXO II | 10 ton | $^{136}X_e$ | |
| GENIUS (77,4K) | 1-10ton | 86% $^{76}Ge$ | 10-1 mev |
| Majorana | 0,5 ton | 86% $^{76}Ge$ | |
| MOON | 1-3 ton | $^{100}Mo$ foils | |

# Lead Radioactivity:

$^{216}$Pb ; $\tau^{1/2}$ = 22,3 y

Common Lead................200 Bq/kg

J&M Lead......................250 mBq/kg

Roman Lead...................$\leq$ 4 mBq/kg